J. Exp. Mar. Biol. Ecol., 161 (1992) 213–222

JEMBE 01814

Swimming performance of captive-reared Kemp's ridley sea turtles *Lepidochelys kempi* (Garman)

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(Received 2 October 1991; revision received 12 March 1992; accepted 19 March 1992)

Abstract: Swimming performance of Kemp's ridley sea turtles *Lepidochelys kempi* (Garman) was evaluated over a 6-month period to determine whether an exercise regime increased swimming capacity in captive reared turtles. Three experimental treatments included: (1) turtles exercised twice weekly and exposed to a weekly stamina test; (2) turtles subjected only to a weekly stamina test; and (3) non-exercised controls exposed to a single stamina test at the end of the study. No statistically significant difference in swimming capacity was detected between treatments 1 and 2, although treatment 1 turtles achieved higher performance levels than those from treatment 2. However, treatment 1 turtles exhibited fewer breaths/min (BRM) and foreflipper strokes/min (FSM) during stamina tests than did treatment 2 turtles. In contrast, control turtles (treatment 3) were unable to achieve the minimum swimming performance level. These results indicate that the swimming performances of exercised turtles significantly improved during captive rearing. The possible effects of an exercise regime on post-release survival potential are discussed.

Key words: *Lepidochelys kempi*; Limb and ventilatory frequency; Sea turtle; Swimming capacity

Introduction

The population of Kemp's ridley sea turtles (*Lepidochelys kempi* (Garman)) has dramatically declined over the past 40 years primarily because of human exploitation (Pritchard & Marquez, 1973) and incidental by-catch by the shrimping industry (Watson & Seidel, 1980; Henwood & Stuntz, 1987; Magnuson et al., 1990). The U.S. and Mexico have been involved in a cooperative program since 1978 to save ridleys from extinction (Klima & McVey, 1982). The program includes, but is not limited to, a head start experiment involving captive rearing hatchlings for 9–11 months at the National Marine Fisheries Service (NMFS) Galveston Laboratory (Fontaine et al., 1989).

Head starting sea turtles increases early survival and growth (Uchida, 1967; Witham & Fitch, 1977; Pritchard, 1980; Nuitja & Uchida, 1982; Caillouet et al., 1986, 1989; Fontaine et al., 1989). It has been suggested that rapid growth produced by head starting might render captive turtles less physically fit than wild turtles because mobility in the rearing container is reduced as anatomical dimensions of the turtles increase

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(Caillouet et al., 1986). However, the effects of rearing methods on the swimming capacity of captive reared sea turtles have not been examined. This study evaluated the swimming performances of exercised and non-exercised turtles to determine if an exercise regime improved the swimming capacity of captive reared turtles.

MATERIALS AND METHODS

EXPERIMENTAL TURTLES AND TEST CHAMBER

Thirty turtles at 3 months of age were selected from a single clutch for swimming performance tests. Ten turtles were randomly assigned to one of three experimental treatments without a priori knowledge of their swimming capacity: (1) turtles exercised twice weekly (Monday and Wednesday) and subjected to weekly stamina testing (Friday); (2) turtles exercised only during weekly stamina testing (Friday); and (3) non-exercised (control) turtles exposed to a single stamina test at the end of the study. All experimental animals were housed in NMFS' head start facilities and administered by an animal care protocol described by Fontaine et al. (1989).

Swimming tests were conducted in a recirculating laminar flow tank modified from that described by Vogel (1981). The test section of the flow tank was 46.4 cm wide × 210 cm long, and contained 246 l of seawater at a depth of 26.3 cm during operation. Current velocities produced in the test section ranged from 0 to 120 $cm \cdot s^{-1}$ and could be regulated to 0.5 $cm \cdot s^{-1}$. Laminar flow in the test section was verified by dye injection at current velocities up to 100 $cm \cdot s^{-1}$. Plexiglass inserts in the test section insured that swimming turtles were exposed only to laminar flow during the test duration. Each experimental turtle was acclimated in the test section 2 min prior to exposure to current flow. The duration of the exercise sessions was increased gradually from 5 to 30 min, and the initial exercise current speed of 12 $cm \cdot s^{-1}$ was increased gradually to 42 $cm \cdot s^{-1}$ over the 21-wk study. Water velocity during stamina tests was increased gradually above the weekly exercise velocity provided to treatment 1 turtles. Stamina tests lasted for 10 min or until the turtle exhibited no swimming activity for 5 min (see below). Current speed for stamina tests began at 16 $cm \cdot s^{-1}$ and was increased 2–6 $cm \cdot s^{-1}$ biweekly over the 21-wk study (Table I).

PERFORMANCE TESTING

Swimming performance was analyzed using three criteria: (1) swimming capacity; (2) breathing rate; and (3) frequency of foreflipper strokes. Swimming capacity, defined as active front flipper movement against a known current velocity for intervals ≥ 2 s, was categorized by: (1) the total swimming time (TST); and (2) the longest interval of continuous swimming (LIS). During swimming capacity evaluations, breathing frequency was measured as the number of breaths per minute (BRM), while frequency of front flipper strokes was determined by the number of foreflipper strokes/min (FSM).

TABLE 1

Test duration and current velocities utilized in stamina test experiments (* equipment malfunction prevented data collection).

Week	Duration (min)	Velocity ($cm \cdot s^{-1}$)
1	10	16
2	10	20
3	10	26
4	10	26
5	10	30
6	10	30
7	10	32
8	10	32
9	10	34
10	10	34
11	10	36
12	10	36
13	10	38
14	*	*
15	10	40
16	10	44
17	10	44
18	10	48
19	10	48
20	10	52
21	10	52

BRM were counted when a turtle lifted its head above the water level, opened its mouth and apparently gulped air.

Non-exercised control (treatment 3) turtles were placed in an exercise regime after completion of the 21-wk study to determine if the standard head starting procedures (Fontaine et al., 1989) influenced their ability to develop swimming capacity, as compared to other 9-month-old captive reared turtles that were exposed to an exercise regime throughout head starting. Only swimming capacity data were collected during these experiments. Turtles were exercised 3 times weekly for 1 month. Exercise duration was 10 min, and current velocities were increased from 18 to 21 $cm \cdot s^{-1}$ after 2 wk of testing.

DATA ANALYSES

Analysis of swimming performance data was restricted to the last 14 wk of stamina tests when the turtles were about 5 months of age. Swimming data were analyzed by designating 25, 50, 75 and 96% of the 10-min test duration as performance levels. For example, a turtle swimming a total of 5 min of the 10-min test period achieved the 50% performance level by TST criteria. In addition, if the longest interval of continuous swimming was ≥ 2.5 min and less than 5 min, the turtle achieved the 25% performance level by LIS criteria. The 96% value was calculated from the mean swimming performance level of the best swimming ridley by TST criteria during a randomly selected month. The number of treatment 1 and 2 turtles achieving each performance level by TST and LIS criteria was then calculated for each of the 14 stamina test periods. Data, grouped by percentage performance levels, were subjected to multi-way contingency tests based on log linear model analyses to test interaction and independence of test date, rearing container and exercise treatment (Sokal & Rohlf, 1981). The effect of rearing container shape on swimming performance is reported elsewhere (Stabenau, 1988).

BRM and FSM were analyzed from the last 11 wk of stamina tests. BRM data were subjected to a square root transformation to ensure that variances were independent of means, and that the transformed data could be treated as normally distributed (Sokal & Rohlf, 1981). FSM data were normally distributed and did not require transformation. Separate multiple classification analyses of variance with factorial arrangements of effects (ANOVA) were conducted for each date to test the effects of exercise treatment on BRM and FSM data. Differences associated with a $p \leq 0.05$ were regarded as significant in all statistical tests.

RESULTS

SWIMMING PERFORMANCE

Swimming capacity was characterized by synchronous movements of the foreflippers during surface swimming, with intermittent periods of non-swimming. Rear flippers acted to maintain position and did not usually aid in propulsion. Swimming capacity varied among turtles, although most turtles achieving high performance levels during exercise sessions performed well in stamina tests. Similarly, turtles swimming poorly during exercise sessions displayed comparably poor swimming performances in stamina tests.

The interaction of test date and exercise category (treatments 1 and 2) in the log-linear model was non-significant ($p \geq 0.05$) for each performance level when analyzed using TST and LIS criteria, thus indicating each effect could be treated and analyzed independently by Goodness of Fit tests (G-statistic). Test date did not affect ($p \geq 0.05$) swimming capacity at each performance level as measured by TST and LIS criteria. Therefore, the number of turtles achieving each performance level within an exercise treatment was combined over the 14 stamina test periods to examine treatment (1 vs. 2) effects on swimming performance. These data are summarized by performance level in Fig. 1.

No statistical difference ($p \geq 0.05$) was found between swimming capacity of turtles exercised twice weekly and exposed to weekly stamina testing (treatment 1) and those of turtles exposed only to weekly stamina testing (treatment 2) by TST and LIS criteria (Fig. 1). Stamina tests appeared to serve the same function in improving fitness (where fitness is defined as the capacity to swim against a known current velocity for a defined period of time) for treatment 2 turtles as exercise sessions did for treatment 1 ridleys. However, the number of treatment 1 turtles achieving each performance level consistently exceeded that of their treatment 2 counterparts (Fig. 1). Approximately 86 and 74% of treatment 1 and 2 turtles, respectively, were capable of swimming 75% of the 10-min test duration measured by TST criteria (Fig. 1A). In contrast, the number of treatment 1 and 2 turtles achieving test criteria decreased at the higher performance levels when analyzed by LIS standards (Fig. 1B). These results suggest that exercised turtles exhibited an intermittent swimming pattern, e.g., prolonged swimming intervals interrupted by periods of non-swimming.

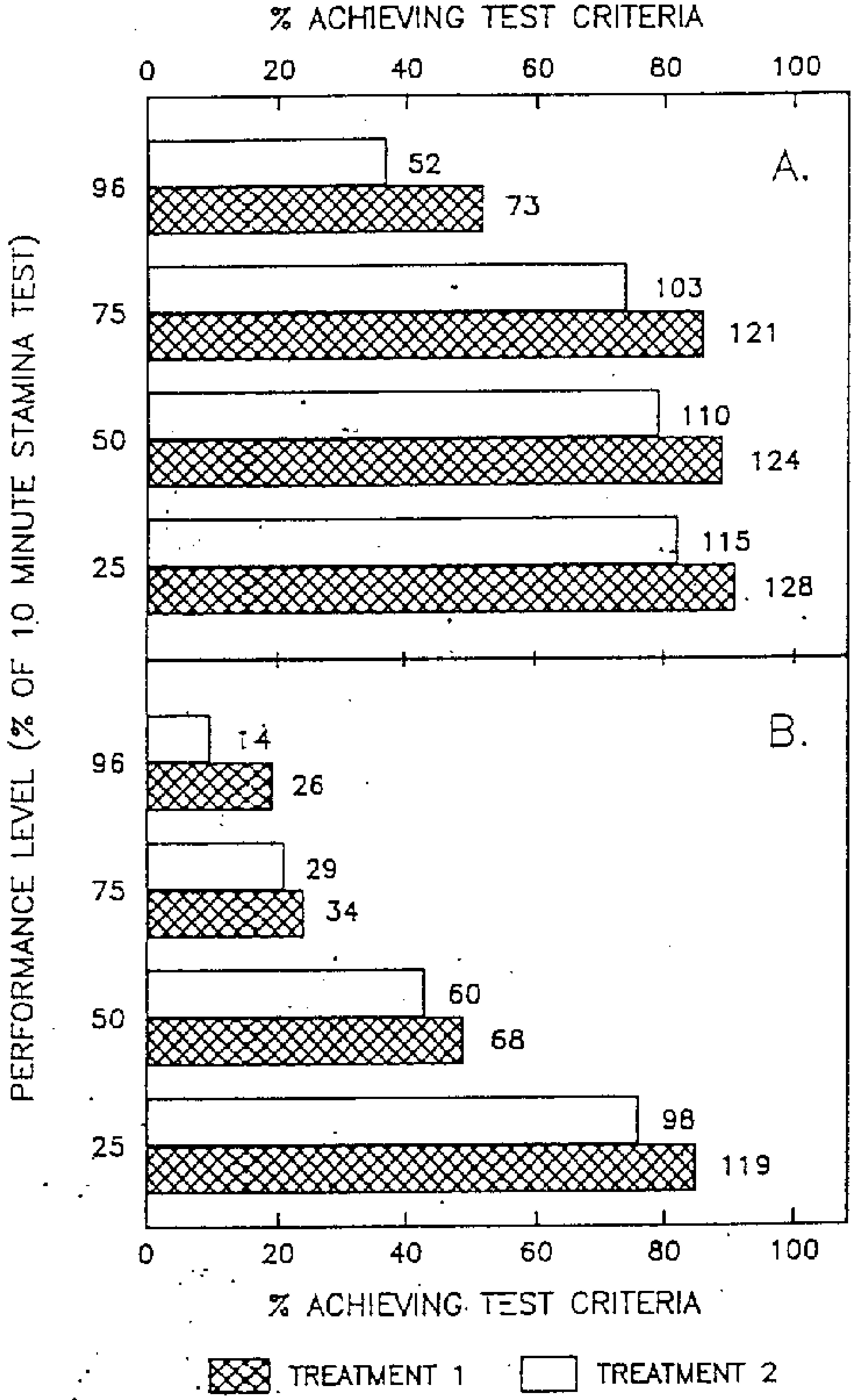

Fig. 1. Percentage of treatment 1 and treatment 2 turtles achieving each performance level by total swimming time (A) and longest interval of continuous swimming (B) criteria. Each pair is not statistically different, $p \geq 0.05$ (each bar is labeled with the number of turtles that achieved the performance levels during 14 weeks of stamina tests).

Nine-month-old treatment 3 turtles (non-exercised controls) were excluded from statistical comparisons because they all failed to achieve the minimum performance level during the final stamina testing date. The maximum performance level attained was only 9.5% (i.e., 57 s of a 10-min test). Moreover, five treatment 3 turtles exhibited defensive postures (tucking foreflippers onto the carapace) and failed to swim against the current stimulus during stamina tests. However, the size of non-exercised turtles was similar to that of exercised turtles on the final test date (Stabenau, 1988); this trend appeared to indicate that lack of exercise did not have a noticeable effect on growth of captive reared turtles.

Treatment 3 turtles exposed to exercise sessions thrice weekly for 1 month were still unable to swim at current velocities exceeding 21 $cm \cdot s^{-1}$. In addition, the maximum performance level achieved by treatment 3 turtles as measured by LIS criteria was 31%, suggesting that the time needed to develop stamina may be protracted by the cumulative effects of captive rearing without an early exercise regime.

LIMB AND VENTILATORY FREQUENCY

There was a disparity between breathing rate and foreflipper stroke frequency for treatment 1 and 2 turtles. Treatment 1 turtles took fewer BRM than did treatment 2 turtles on 10 of 11 (90.9%) stamina tests, and significant differences in BRM between treatments occurred 36.4% (4 of 11) of the time (Fig. 2). A comparable trend existed for foreflipper stroke frequency between treatments. Treatment 1 turtles exhibited fewer FSM than did treatment 2 turtles during all stamina tests, and 72.7% (8 of 11) were significantly different (Fig. 3). However, there was no consistent pattern in the frequency of breathing and foreflipper strokes of treatment 1 and 2 turtles over the 11 stamina tests (Figs. 2 and 3). Generally, treatment 1 turtles averaged 35 breaths and

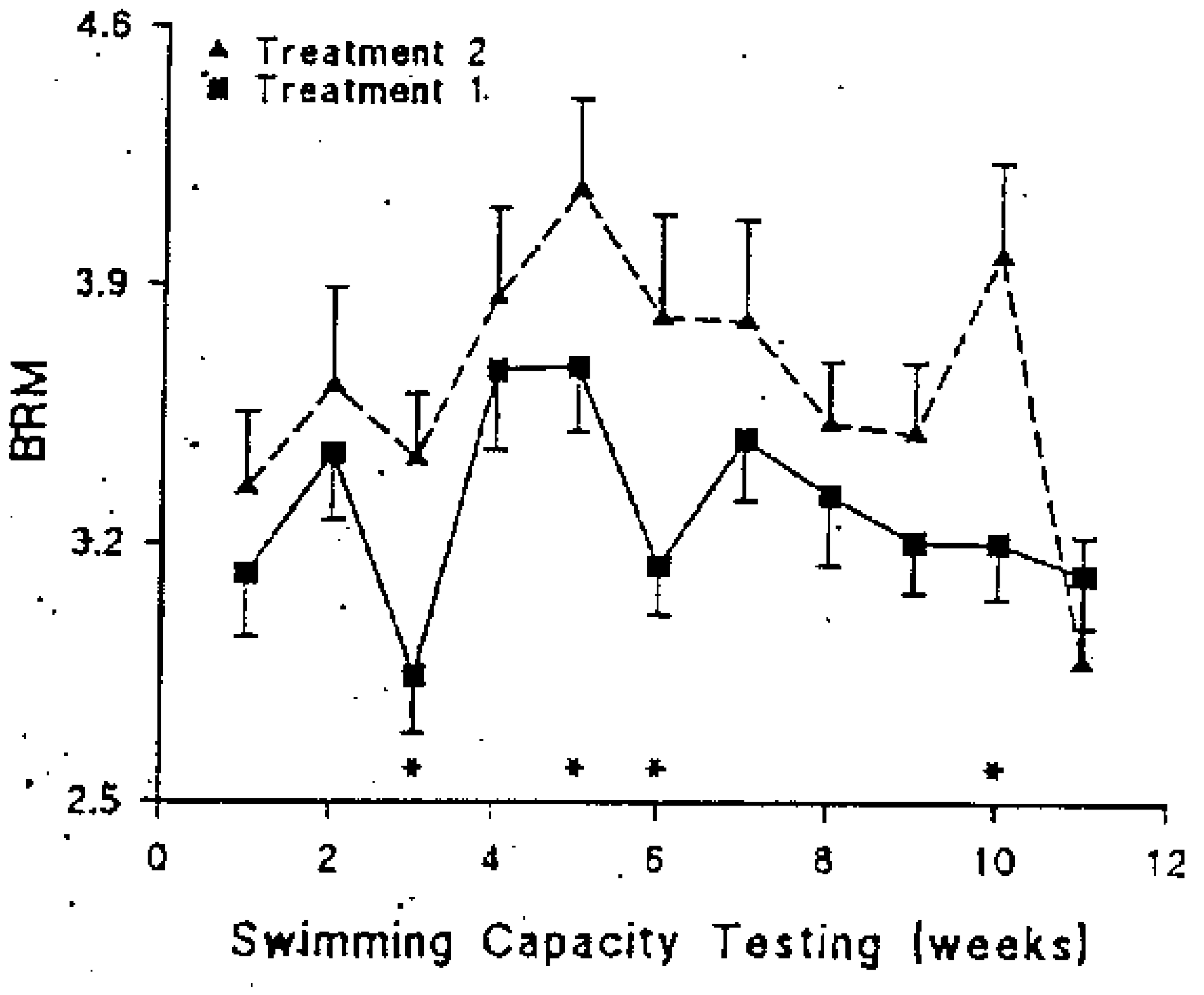

Fig. 2. Breathing frequency (BRM; Mean ± SE) exhibited by treatment 1 and treatment 2 turtles over 11 weeks of stamina testing. Significant differences ($p \leq 0.05$) are indicated by asterisks.

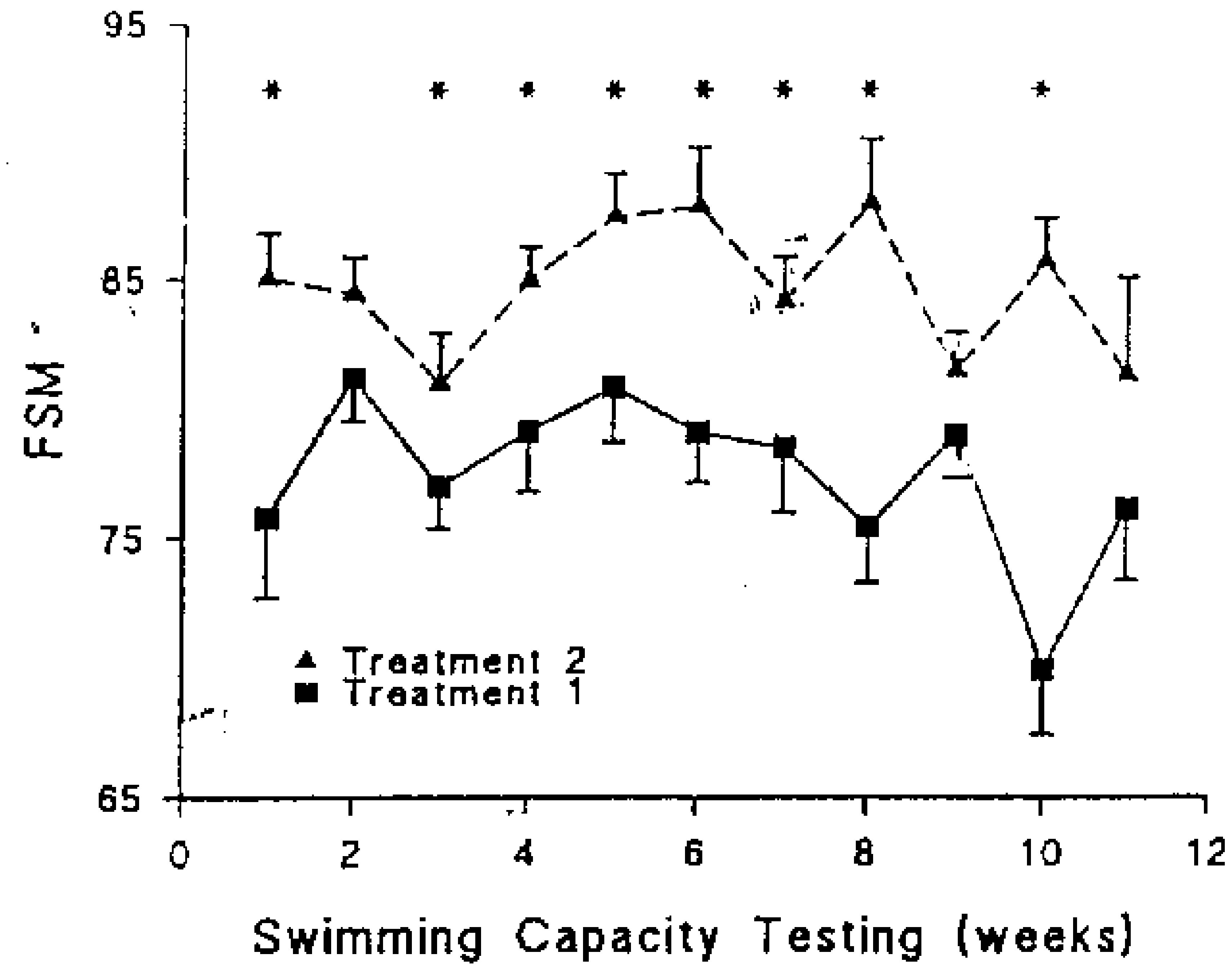

Fig. 3. Frequency of foreflipper strokes (FSM; Mean ± SE) exhibited by treatment 1 and 2 turtles over 11 weeks of stamina testing. Significant differences ($p \leq 0.05$) are indicated by asterisks.

800 foreflipper strokes during the 10-min stamina tests, whereas treatment 2 turtles averaged 40 breaths and 850 foreflipper strokes.

Discussion

There was no statistical difference in swimming capacity between exercise treatments 1 and 2, although the performance of treatment 1 turtles consistently exceeded that of treatment 2 turtles. In addition, the frequency of BRM and FSM exhibited by treatment 1 turtles was routinely less than that displayed by treatment 2 turtles. These results suggest that weekly exercise sessions improved swimming performance beyond that provided by weekly stamina tests alone. In contrast, treatment 3 turtles failed to achieve any of the swimming performance levels. The disparity in swimming performances between exercised (treatments 1 and 2) and non-exercised (treatment 3) turtles should not be overlooked. Although an assessment of survival of head started turtles after release into the wild was beyond the scope of this research, the limited swimming capacity in control turtles during laboratory tests may be indicative of a potential for limited performance upon release. The control turtles represented the standard rearing practices used at the NMFS Galveston Laboratory (Fontaine et al., 1989), and they may not have developed a swimming capacity sufficient to withstand current velocities of 50 $cm \cdot s^{-1}$ in the Gulf of Mexico (Hann et al., 1985) or the stamina to escape all predators, elude shrimp trawls, or capture adequate food. Studies on captive reared fish have revealed that prior exposure to current flow decreased post-release mortality (Cresswell & Williams, 1983). Exercised turtles may be more capable of predator and shrimp trawl avoidance and swimming long distances than non-exercised turtles, and hence, have higher post-release survival potential. While the ability to perform (or not perform) under laboratory conditions does not assure similar performance in the wild, the swimming capacity of captive reared turtles scheduled for release should not be ignored by sea turtle management programs in the future.

There are two possible explanations for poor swimming performances by control turtles. First, control turtles were physically unable to swim against the experimental current velocity of the final stamina test, and thus, were limited by exercise deprivation. Second, control turtles were not exposed previously to current flow, and hence, responded to the current stimulus in a different manner than treatment 1 and 2 turtles that were conditioned to current flow on a weekly basis. Development of swimming capacity in exercised turtles may have been influenced in part by the learning experience of repeated current flow exposure, and thus, led to increased physical fitness. Furthermore, control turtle swimming performance improved after exposure to an exercise regime. It was beyond the scope of this study, however, to determine if they were developing the physical capacity to perform or if current flow exposure resulted in a learned (i.e., trained or conditioned) response. Nevertheless, improvement in swimming performance suggests that the effects of previous exercise deprivation might be able to be reversed, given sufficient exercise over time.

Treatment 1 and 2 turtles at 3 months of age responded to the stimulus in this study by orienting into and swimming against the initial stamina test current flow of 16 $cm \cdot s^{-1}$. This rheotactic behavior continued at 9 months of age at a current velocity of 52 $cm \cdot s^{-1}$. We will not speculate on the swimming activity of these turtles in the wild, and there is no information on the swimming behavior of wild Kemp's ridley turtles to a current stimulus (see below). Hatchling loggerhead turtles, however, responded to surface stimuli by swimming into approaching waves and swells in laboratory (Wyneken et al., 1990) and field experiments (Salmon & Lohmann, 1989). In addition, Wibbels (1984) recorded the movements of non-conditioned captive reared yearling Kemp's ridley sea turtles in the Gulf of Mexico using radio tracking techniques, and reported that the turtles were swimming against the current. The non-conditioned turtles used by Wibbels (1984), therefore, responded to a current stimulus in a comparable manner to the treatment 1 and 2 turtles used in this study. These results suggest that treatment 3 turtles did not have the capacity to swim against the current flow of the final stamina test, rather than the alternative explanation that control turtles exhibited the appropriate response to flow by not swimming into the current. Furthermore, treatment 3 turtles were positively rheotactic at the reduced current velocity of 18 $cm \cdot s^{-1}$.

Little direct evidence is available as to whether wild Kemp's ridley sea turtles disperse with or against prevailing currents. The major currents along the eastern North American coast generally move in a northern direction (Carr, 1987). However, juvenile turtles tagged in the Cape Canaveral, Florida region move north with warming water, and then south as water temperatures drop in the winter (Henwood & Ogren, 1987). This pattern suggests that wild Kemp's ridley sea turtles have the capacity to swim against surface stimuli. It is possible, therefore, that the survival potential of exercised head-started Kemp's ridley turtles would be increased by the physical capacity to swim against surface stimuli when necessary (e.g., with changes in water temperature).

There may have been limitations to using turtles from one clutch in this experiment. Comparable swimming performances between treatment 1 and 2 turtles, and poor swimming performances by treatment 3 turtles, may not have been obtained if other clutches were used simultaneously. Experimental turtles, however, were selected from one clutch to eliminate uncontrollable interclutch variability, and turtles were randomly chosen without a priori knowledge of their swimming capacity.

Breathing data exhibited by Kemp's ridleys during swimming performance tests were similar to those reported for nesting green sea turtles (Jackson & Prange, 1979). However, the mean breathing frequency for Kemp's ridleys was higher than that reported for green turtles engaged in similar laboratory swimming (Butler et al., 1984). In addition, the frequency of foreflipper strokes exhibited by Kemp's ridley sea turtles was less than that for 1-day-old green and loggerhead sea turtles (Salmon & Wyneken, 1987). Interspecific comparisons of breathing and limb cycle counts with other studies are difficult because of dissimilar turtle sizes and experimental protocols.

ACKNOWLEDGEMENTS

This study was completed by the senior author (E.K. Stabenau) in partial fulfillment of the requirements for the M.Sc. degree, Department of Wildlife and Fisheries Sciences, Texas A&M University. Partial financial support was provided by Texas A&M University Sea Grant College Program and HEART (Help Endangered Animals-Ridley Turtles) Fellowships to E.K. Stabenau. The NMFS Galveston Laboratory graciously provided experimental turtles and facilities to perform the research project. Appreciation is expressed to undergraduate students at Texas A&M University at Galveston who assisted in collection and subsequent computer entry of data. T.A. Heming, D.W. Owens, and two anonymous reviewers provided valuable comments on the manuscript.

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